Human Perception and Cognition

Preparing the psychophysical experiment

Once we have obtained the RGB color images from the spectral cubes in the previous section, we will design a psychophysical experiment using the Psychotoolbox Framework.

The structure of the experiment:

1) We will select the RGB image obtained with SpecimIQ camera as our reference to develop our psychophysical experiment.

2) The experiment will consist of finding the threshold stimulus in which a standard observer is able to detect a change in the hue or chroma in the reference image. In order to accomplish this, we will use the Constant Stimuli Method, and we will run a psychophysical experiment with 10 standard observers. In this way, we will generate some psychometric functions, which will help us to approximate the threshold stimuli. Note that, despite we could use the Methods of Limits to find the psychometric functions using fewer number of trials compared to the Method of Constant Stimuli. We prefer the second one because this method allow us to reduce the bias due to presenting stimuli in a fixed order.

3) Now, before running the psychophysical experiment, we need to prepare the image sets which will contain images created from distorting the original image in different ways and levels.

   In order to do so, the original image will be converted to CIELAB and then to CIEHLC representation. The CIEHLC color space uses Chroma(C), Hue(H) and Lightness(L) to represent the colors. Notice that CIEHLC is the polar coordinates representation of CIELAB color space (which uses cartesian coordinates). Therefore, the respective conversion is carried out as follows:
   From CIELAB to CIEHLC (From cartesian to polar coordinates)

$$C^\star = \sqrt{a^{*2} + b^{*2}} \qquad h^\circ = \operatorname{atan2}(b^*, a^*)$$

   From CIEHLC to CIELAB (From polar to cartesian coordinates)

$$a^\star = C^\star \cos(h^\circ) \qquad b^\star = C^\star \sin(h^\circ)$$

   The value of L is the same for both CIELAB and CIEHLC.
   The range of a and b values of CIELAB is [-128, 127) and the range of L is [0, 100]. Also, we will use degrees (not radians) to represent the Chroma of CIEHLC.

   After having the CIEHLC representation of our reference image, we will distort it in 4 different ways.

   a. Increasing Hue:
      Maximum of 10 Steps and offset size of +4 degrees per step.

b. Decreasing Hue:
   Maximum of 10 Steps and offset size of -4 degrees per step.
c. Increasing Chroma:
   Maximum of 10 Steps and offset size of +2 units per step.
d. Decreasing Chroma:
   Maximum of 10 Steps and offset size of -2 units per step.

Once we have generated the distorted versions of the original image, we will convert them back to the RGB color space. In this way, will generate 4 different image sets (Blocks) each with 10 different versions of the image.

4) Now that we have the four different image data sets (Blocks), we will perform the psychophysical experiment with our 10 observers and average between them. In fact, the experiment is made up of 4 different sub-experiments (one for each image set block). In this way, we will be able to generate 4 different psychometric functions: one for positive hue displacement, one for negative hue displacement, one for positive chroma displacement, and one for negative chroma displacement. In the end, we will analyze the four psychometric functions independently, and we will also analyze the relationships between them.

So, during the experiment, the participant will observe the following type of screen and, he will have to press “Left arrow key” if both images seem equal or “Right arrow key” if they seem different.

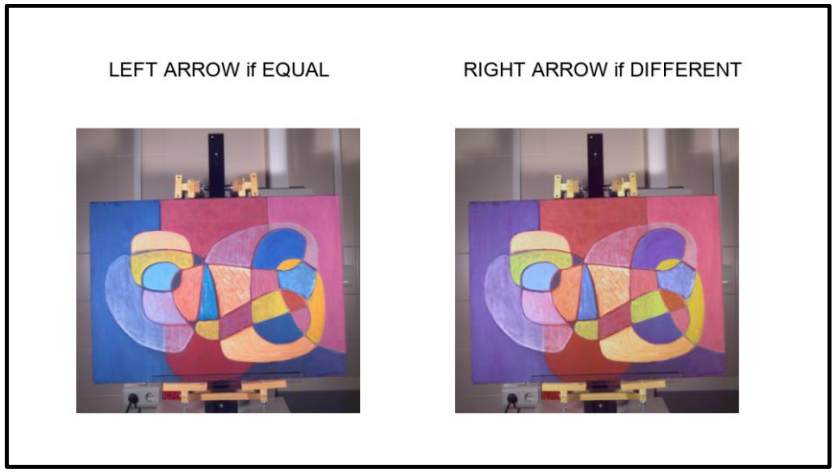

Figure 1. Example of the screen shown to the observer for one trial

Each one of these screens will show the original image together with one of the images of the current image data set. Notice that to prevent the viewer from getting used to a default position of the original image, the left or right position of both images varies randomly from screen to screen.

Also, consider that each pair of images will be shown 5 times in order to calculate the "probability of perceiving the stimulus" at that specific level. Then, the observer will have to complete 50 trials per sub-experiment (Block). So, because we have 4 sub-experiments, each observer will have to complete a total of 200 screens to finish all the psychophysical experiments.

5) In addition, we will use the CIE76 formula to calculate the average color difference of all the pixels between each distorted image and the original image. Note that despite CIE76 formula is a good option to calculate color differences between color patches, it is not effective for analyzing differences between whole images (since it does not consider spatial information). For that reason, we will also use the S-CIELAB Delta E Metric which takes into account the spatial information of the images.

Analysis of the results

After completing the psychophysical experiment with our 10 observers, in this section, we will show and analyze the results. Consider that these results are just approximations because this experiment was not performed in a laboratory environment with controlled conditions. Then, the results can vary considerably between each observer, since each one has completed the experiment in their own environment and used their own screen settings: quality of the screen, brightness, contrast, distance to the screen, etc.

A) Increasing Hue

BLOCK 1 (Increasing Hue)				
Shift (Degrees)	AVERAGE CIE76	AVERAGE S-CIELAB	Probability of perceiving the difference	Average reaction time (Seconds)
0	0	0	0.00	2.067
4	1.9069	1.7484	0.00	2.054
8	3.8115	3.5347	0.12	4.534
12	5.7115	5.3549	0.52	3.243
16	7.6045	7.1934	0.84	1.863
20	9.4882	9.0375	0.96	1.670
24	11.3604	10.8946	0.98	1.574
28	13.2187	12.7486	1.00	1.183
32	15.061	14.6053	1.00	0.923
36	16.8848	16.4585	1.00	0.845

Table 1. Results of the experiment of increasing hue

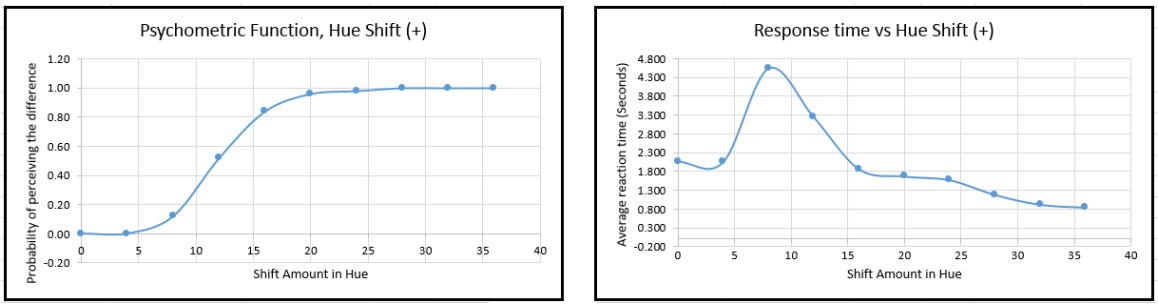

Figure 2. At the left, the psychometric function of the experiment of increasing hue. At the right, the average response time

In this case, we found the threshold at +12 shift degrees, since at this value, the probability of perceiving the difference was 50% (approximately). Also, another interesting fact that we could notice here is that the average response time (time elapsed before an observer makes the decision) is higher for the trials located near the threshold compared to the trials located considerably above or below the threshold.

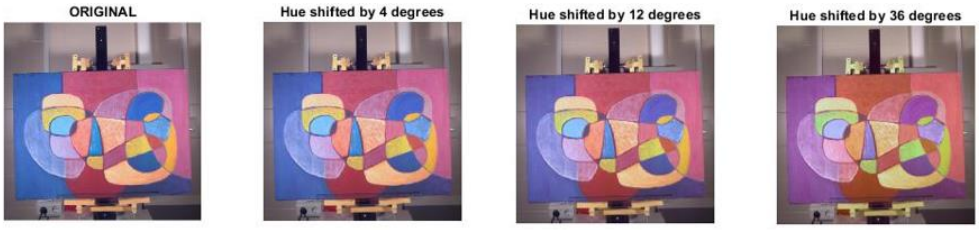

Figure 3. Original image and three examples of the resulting image versions when increasing the hue.

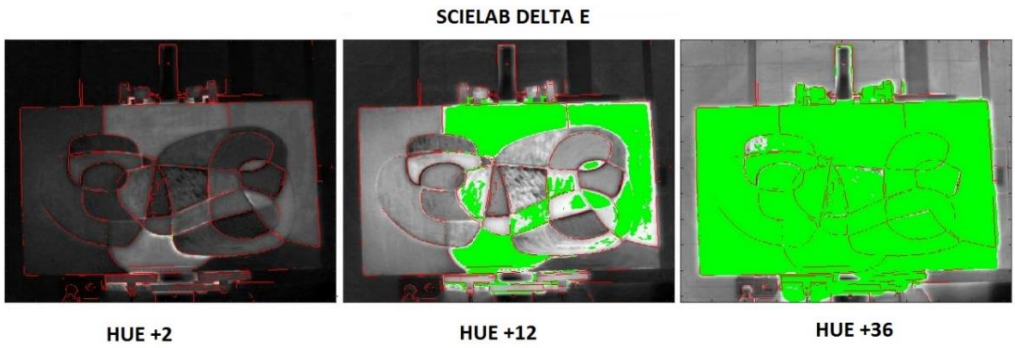

Figure 4. S-CIELAB Delta E obtained between the original image and three altered versions by increasing the hue.

In Figure 4, we can observe three S-CIELAB image difference calculations. In the case of the left image, it was calculated between the original image and the image with hue shifted by +2 degrees. In the case of the center image, it was calculated between the original image and the image with hue shifted by +12 degrees (corresponding to the threshold). Finally, in the case of the right image, it was calculated between the original image and the image with hue shifted by +36 degrees. The dark pixels represent a small S-CIELAB Delta E value, while the light pixels represent a high S-CIELAB Delta E value. The red lines are just for better visualization of the edges in the image, and they were calculated independently based on the original image. Finally, the green pixels represent the location of very high S-CIELAB Delta E differences, for this experiment, we will consider within this category all the S-CIELAB Delta E values equal to or greater than 20. We have used this value because it is the one suggested by the author of the S-CIELAB algorithm that we have used as a basis for this calculation (http://scarlet.stanford.edu/~brian/scielab/scielab.html).

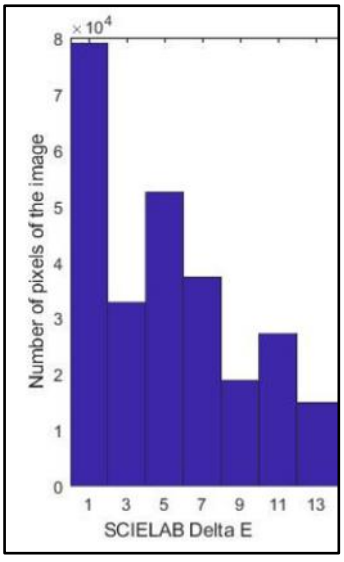

Figure 5. Histogram of S-CIELAB Delta E (For hue shifted by +12 degrees)

Finally, Figure 5 shows a histogram with the values S-CIELAB Delta E of the image with hue shifted by +12 degrees (the last column corresponds to the values equal to or greater than 12). Notice that there is a high number of pixels with S-CIELAB Delta E value between 0 and 2. Then, if we check Figure 4, we can notice that the majority of those pixels correspond to the background of the image. While if we look at the painting itself, we can notice that here are the highest S-CIELAB Delta E values marked in light pixels or even green if they are greater than 20.

B) Decreasing Hue

BLOCK 2 (Decreasing Hue)				
Shift (Degrees)	AVERAGE CIE76	AVERAGE S-CIELAB	Probability of perceiving the difference	Average reaction time (Seconds)
0	0	0	0.00	1.322
-4	1.9069	1.6923	0.00	1.414
-8	3.8115	3.3436	0.12	2.079
-12	5.7115	4.9779	0.46	2.316
-16	7.6045	6.5904	0.82	1.946
-20	9.4882	8.1841	0.94	1.634
-24	11.3604	9.7596	0.98	1.432
-28	13.2187	11.3213	1.00	1.234
-32	15.061	12.8705	1.00	1.022
-36	16.8848	14.4027	1.00	0.884

Table 2. Results of the experiment of decreasing hue

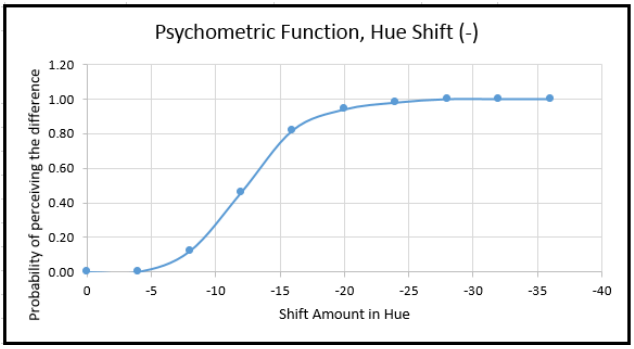

Figure 6. Psychometric function of the experiment of decreasing hue

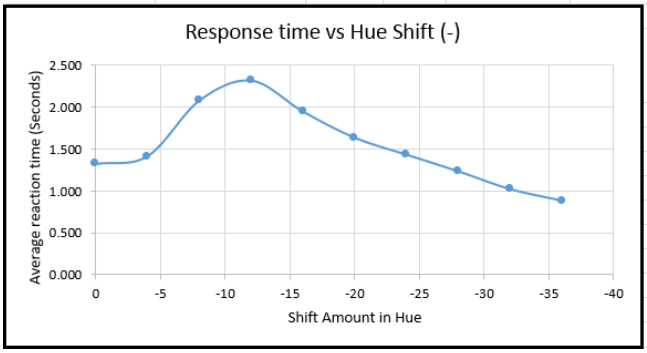

Figure 7. Average response time of the experiment of decreasing hue

In this case, we found the threshold at -12 shift degrees, since at this value, the probability of perceiving the difference was 50% (approximately). And in the same way as in the previous experiment, we could notice that the average response time is higher for the trials located near the threshold compared to the trials located considerably above or below the threshold.

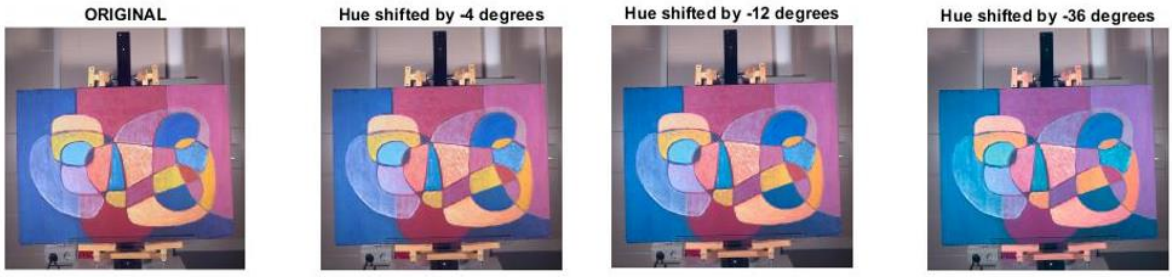

Figure 8. Original image and three examples of the resulting image versions when decreasing the hue.

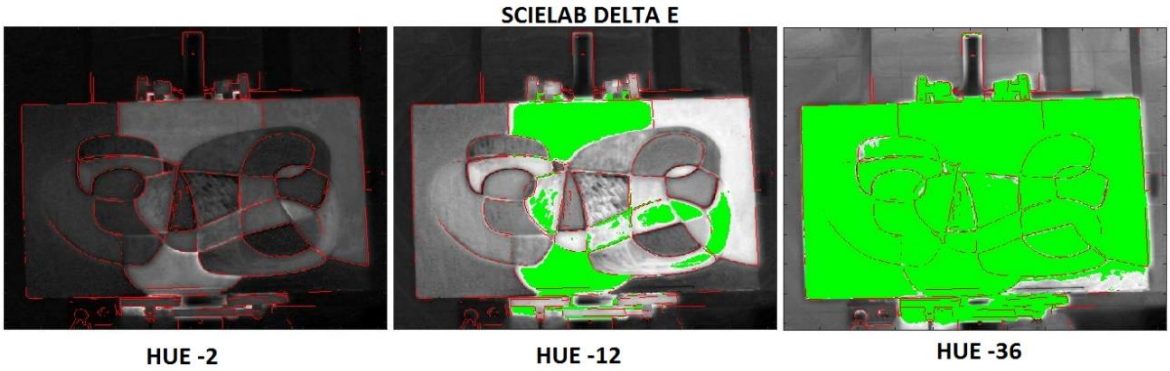

Figure 9. S-CIELAB Delta E obtained between the original image and three altered versions by decreasing the hue.

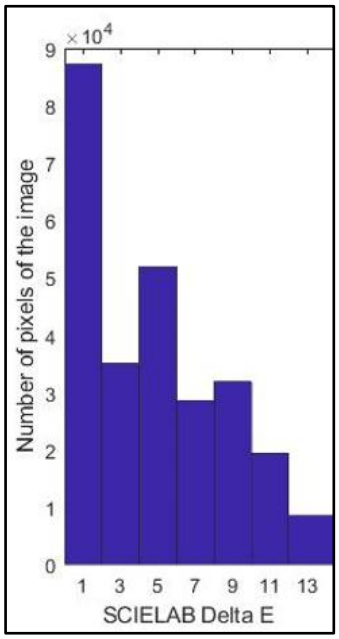

Figure 10. Histogram of SCIELAB Delta E (For hue shifted by -12 degrees)

C) Increasing Chroma

BLOCK 3 (Increasing Chroma)				
Shift	AVERAGE CIE76	AVERAGE S-CIELAB	Probability of perceiving the difference	Average reaction time (Seconds)
0	0	0	0.00	1.893
2	2	2.0664	0.00	1.952
4	4	4.1214	0.06	1.900
6	6	6.1592	0.22	2.230
8	8	8.1814	0.48	3.300
10	10	10.1736	0.82	1.341
12	12	12.1288	0.96	0.945
14	14	14.0473	1.00	0.751
16	16	15.9298	1.00	0.700
18	18	17.7728	1.00	0.715

Table 3. Results of the experiment of increasing chroma

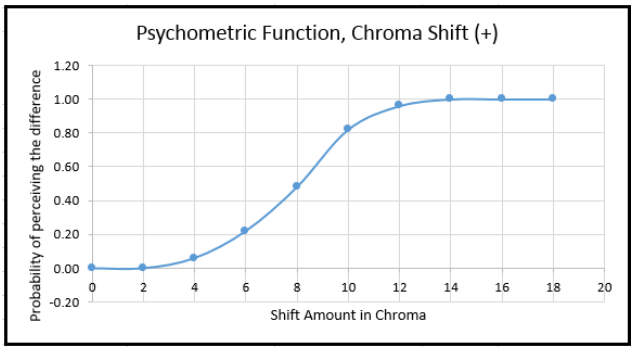

Figure 11. Psychometric function of the experiment of increasing chroma

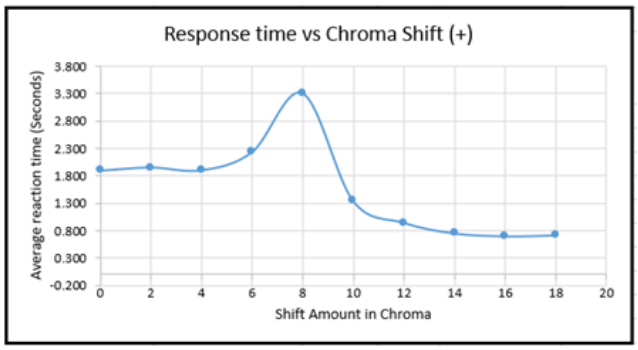

Figure 12. Average response time of the experiment of increasing chroma

In this case, we found the threshold at +8 shift units, since at this value, the probability of perceiving the difference was 50% (approximately). And in the same way as in the previous experiments, we could notice that the average response time is higher for the trials located near the threshold compared to the trials located considerably above or below the threshold.

Figure 13. Original image and three examples of the resulting image versions when increasing the chroma.

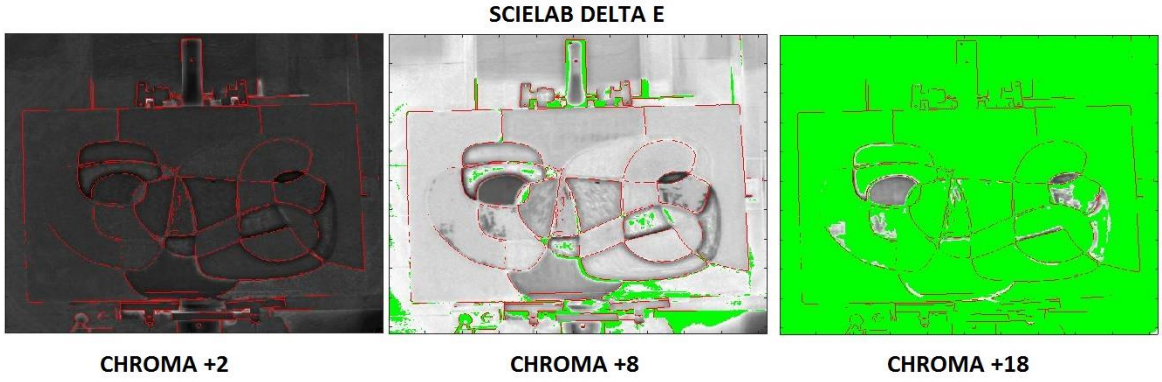

Figure 14. S-CIELAB Delta E obtained between the original image and three altered versions by increasing the chroma.

If we analyze Figure 14, we can notice that the S-CIELAB Delta E image corresponding to this chroma alteration threshold is very different from the previous two obtained in the hue alteration experiments (Shown in Figures 4 and 9). In this way, the main difference is that the background has higher S-CIELAB Delta E values compared to the hue alteration experiments. For that reason, the pixels of the background are represented as lighter as the pixels of the painting in the central image of Figure 14. This is also reflected in the histogram in Figure 15, where we see that the differences are concentrated between 6 and 10 (S-CIELAB Delta E). This is very different from the histogram of the hue alteration experiments (Shown in Figures 5 and 10), since in those cases the differences were concentrated between 0 and 2.

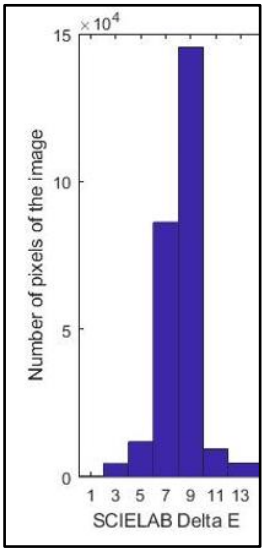

Figure 15. Histogram of S-CIELAB Delta E (For chroma shifted by +8 units)

D) Decreasing Chroma

BLOCK 4 (Decreasing Chroma)				
Shift	AVERAGE CIE76	AVERAGE S-CIELAB	Probability of perceiving the difference	Average reaction time (Seconds)
0	0	0	0.00	1.653
-2	2	2.0664	0.00	1.820
-4	4	4.1257	0.04	2.365
-6	6	6.181	0.24	2.857
-8	8	8.2291	0.62	2.667
-10	10	10.2704	0.90	1.916
-12	12	12.3045	0.98	1.227
-14	14	14.3281	1.00	0.959
-16	16	16.3413	1.00	0.791
-18	18	18.3329	1.00	0.723

Table 4. Results of the experiment of decreasing chroma

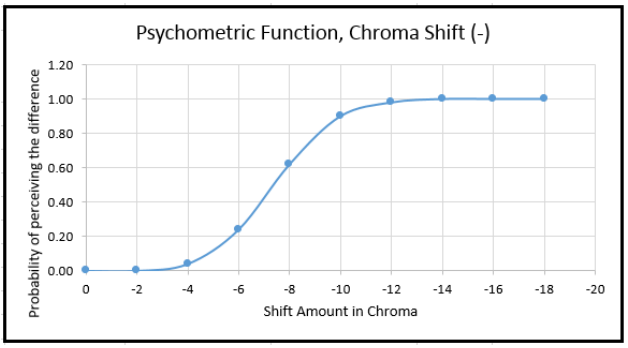

Figure 16. Psychometric function of the experiment of decreasing chroma

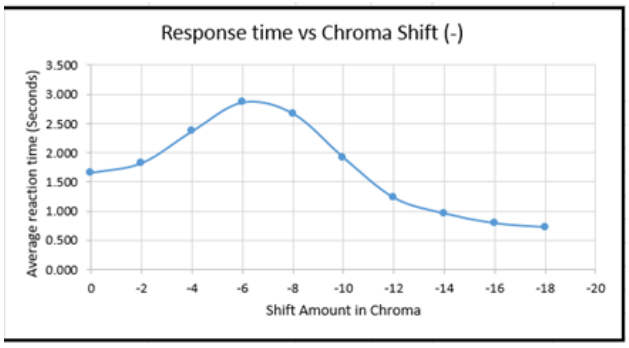

Figure 17. Average response time of the experiment of decreasing chroma

In this case, we found the threshold at -8 shift units, since at this value, the probability of perceiving the difference was 50% (approximately). And in the same way as in the previous experiments, we could notice that the average response time is higher for the trials located near the threshold compared to the trials located considerably above or below the threshold.

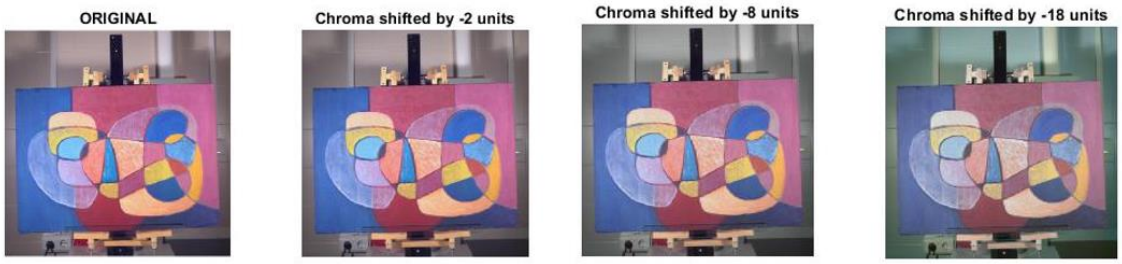

Figure 18. Original image and three examples of the resulting image versions when decreasing the chroma.

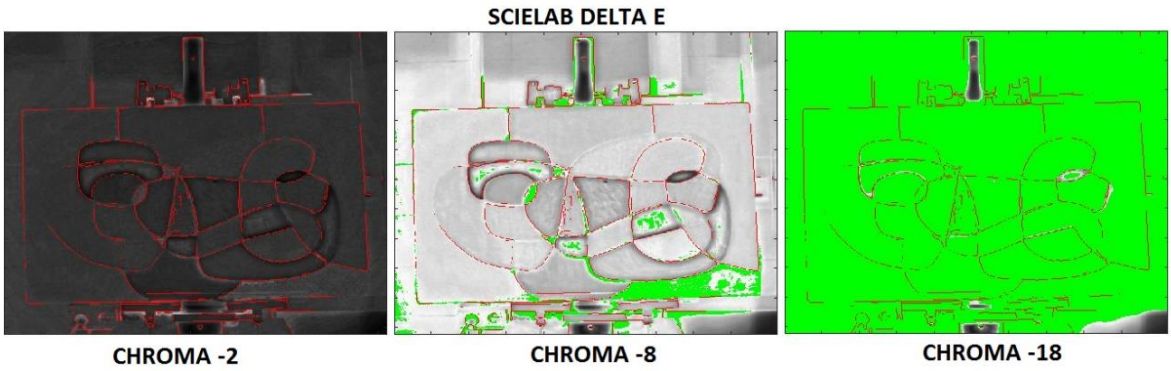

Figure 19. S-CIELAB Delta E obtained between the original image and three altered versions by decreasing the chroma.

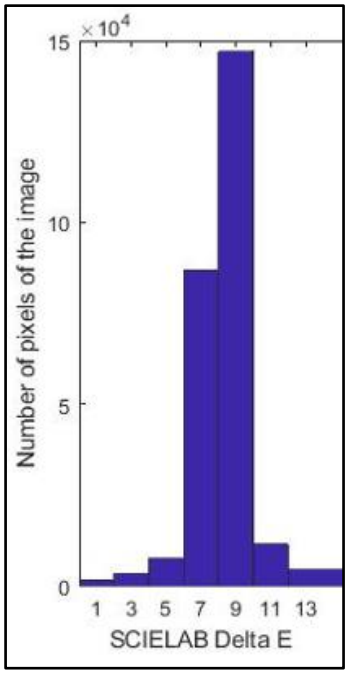

Figure 10. Histogram of S-CIELAB Delta E (For chroma shifted by -8 units)

Conclusions

In this work, a psychophysical experiment has been implemented in order to find thresholds when modifying the hue and chroma values of an image of a painting. The input image used was in RGB format, it was captured with hyperspectral technology and pre-processed in the previous section corresponding to the "Advance Color and Hyperspectral Imaging" course.

Thus, the applied psychophysical experiment was the Method of Constant Stimuli, in which the observers were asked to say whether or not they perceived the difference between two images (the original and the modified one at different levels). So, the general experiment consisted of 4 sections. The first one is dedicated to finding the threshold when the hue of the image has been positively shifted (Increase Hue). The second section similar to the first section but with negative steps (Decrease Hue). The third section is dedicated to finding the threshold when the chroma of the image has been positively shifted (Increase Chroma). And the last section similar to the previous one but with negative steps (Decrease Chroma).

This experiment was applied to 10 standard observers and an average was calculated. It is important to mention that the results obtained are simple approximations since they could be highly biased due to the uncontrolled conditions of the experiment. Since it was not performed in a laboratory environment, important factors such as: screen brightness, screen quality, screen size, observer-screen distance, ambient lighting, could not be controlled.

At the end of the experiments, we were able to generate 4 psychometric functions: one for positive hue displacement, one for negative hue displacement, one for positive chroma displacement, and one for negative chroma displacement. In the hue case, we found the threshold stimulus at 12 shift degrees approximately (for both positive and negative displacements). While in the chroma case, we found the threshold stimulus at 8 shift units approximately (for both positive and negative displacements).

Also, another interesting fact that we noticed was the relationship between the response time and the psychometric function. In all four experiments, it was noted that the closer the stimulus is to the threshold, the response time of the observer will be slightly higher. This makes sense since it is much more difficult for the observer to decide near the threshold, compared to stimuli very far from the threshold which are decided almost immediately.

Finally, unlike the normal CIE76 formula which is designed to compare uniform color patches, thanks to S-CIELAB Delta E we were able to analyze the differences between the original image and the altered images considering the spatial information. Thus, we note how in the hue alteration experiments the background did not play such an important role in perceiving the differences between the original and the altered image, compared to the region corresponding to the painting (The most colorful region of the image). Furthermore, we saw that the value of the difference between the reddish regions was higher than the values of the difference between the bluish regions. In the chroma alteration experiments, we saw that both the background and the painting have approximately the same importance for the comparison between the original image and the altered images.

For future works, it would be good to replicate these psychophysical experiments but in controlled conditions. In this way, we would obtain more accurate psychometric functions. Also, it would be good to perform these experiments with a wide set of varied images, in this way we could generalize our results and not limit them to a single image.